Electric field induced second harmonic generation in germanium doped silica planar waveguides

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Indexing terms: Optical harmonic generation, Optical waveguides, Silicon dioxide

Instantaneous frequency doubling is demonstrated in germania doped silica planar waveguides deposited on fused silica substrates by quasi-phasematching with an externally applied, periodic DC field. The DC field periodicity which causes frequency doubling corresponds to the beat length between the fundamental and second harmonic light propagating in the waveguide.

Introduction: Photoinduced efficient frequency doubling of 1.064 µm radiation was first observed in germanium doped silica fibres in 1986 [1]. Recently this has also been achieved in planar dielectric waveguides made from the same materials [2]. All of the proposed theories to explain this phenomenon are based on the original hypothesis of Stolen and Tom that the photoinducing process creates a permanent internal DC electric field which breaks the inversion symmetry in the glass resulting in an effective $\chi^{(2)}$ and that the periodicity of this field provides the quasi-phasematching necessary for efficient SHG [3].

In 1989, Kashyap [4] applied an external periodic DC field to the exposed core of an optical fibre and was able to induce instantaneous SHG which was controlled by the applied voltage. In 1975, Levine and Bethea [5] achieved SHG by applying a periodic electric field to a liquid planar waveguide. In this Letter we present the results of using a similar technique on a planar dielectric waveguide. The planar waveguide, quasi-phasematched frequency doubler presented in this Letter has the advantage over the fibre technique of being easily fabricated using standard photolithography techniques and can be manufactured simultaneously with other integrated optical components.

To provide the correct periodicity for quasi-phasematching, the nonlinearity must be strong only at points where the fundamental and second harmonic are in-phase. This periodicity Δz is given by the expression

$$\Delta z = \left|\frac{2\pi}{2\beta_\omega - \beta_{2\omega}}\right| \quad (1)$$

where β_ω is the propagation constant for the IR light and $\beta_{2\omega}$ is the propagation constant for the green light. If prisms are used to couple light into the waveguide, the propagation constants can be determined experimentally from the prism coupling angles using the equation

$$\beta = n_p k_0 \cos\theta_p \quad (2)$$

where n_p is the prism refractive index, θ_p is the incidence angle of the light internal to the prism and k_0 is the optical wavenumber in free space.

Description of experiment: The waveguides used to obtain the results in this paper were fabricated using argon ion beam sputtering of silica and germanium onto commercial, optical grade fused silica substrates. The sputtering rate was 0.11 nm/s in a partial pressure of 10^{-4} torr of oxygen. The film used in this study was ~3.5µm thick. Auger analysis indicated that the GeO_2 content of the film was ~6m%. The refractive index of the substrate is 1.4607 at 0.532µm and 1.4496 at 1.064µm. The refractive index of the film was measured to be 1.546 at 0.532µm and 1.532 at 1.046µm using the prism coupling method.

For these experiments, an interdigitated electrode structure was mounted above the waveguide, as illustrated in Fig. 1. The experimental setup is illustrated in Fig. 2. The output from a Q switched (1kHz), modelocked (100MHz, 200ps pulse FWHM) Nd:YAG laser is coupled into the waveguide. The output SH signal is detected with a photomultiplier and averaged with a boxcar integrator.

To test the device, the voltage source is applied to the electrode structure, IR light is coupled through the waveguide and the angle of the electrodes with respect to the optical path is varied in order to optimise the detected SH signal. By adjusting the angle of the electrodes, the effective periodicity can be modified. Once the SH signal is optimised, the SHG is measured as a function of applied voltage.

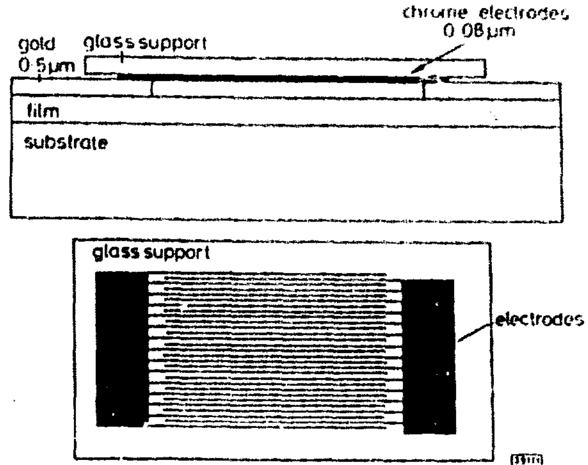

Fig. 1 *Periodic electrode structure and placement relative to planar waveguide*

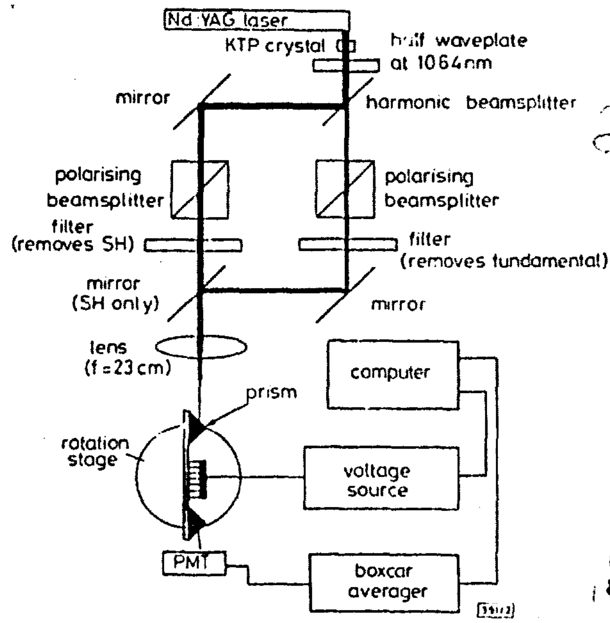

Fig. 2 *Experimental setup for EFISH measurements*

SH from crystal is used to align PMT with correct mode in green and is blocked during EFISH measurement
◊ measured EFISH
– – – voltage squared

Results: By measuring the prism coupling angles for green and IR, it was determined that the quasi-phasematching period for the 3.5 µm waveguide is 26.7µm. This was for the lowest order TM mode in both the green and IR. We found the greatest SHG on the 3.5 µm thick waveguide using an interdigitated electrode structure with 384 digits having a 26µm periodicity which was rotated 7.9° to the optical path. The individual electrode fingers were 3µm wide and the gaps were 10µm between fingers. This provides an effective electrode periodicity of ~26.25µm. The maximum SHG with 50V applied across the electrodes was a visible green spot at the correct angle to indicate that it was in the TM_0 mode. The average power used was 15mw of IR light and resulted in 0.1nW of green. With the electrode periodicity fixed at 7.9°, the SHG was measured as a function of applied voltage (Fig. 3). The observed quadratic dependence of the electric field induced SHG intensity with voltage is expected from $\chi^{(3)}$ EFISH.

We were also able to generate a signal in the TM_1 mode in this

film by changing the electrode periodicity to 70μm, close to the calculated quasi-phasematching period for this mode. It is several orders of magnitude lower than that observed for the TM_0 mode.

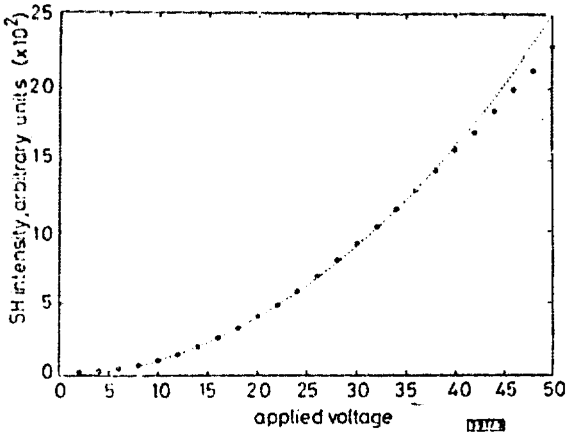

Fig. 3 *Generated second harmonic as function of applied voltage*

Input IR is in TM_0 mode and output green is detected in TM_0 mode

Conclusions: We have presented a device consisting of a germanium doped glass waveguide and a periodic electrode structure which is capable of instantaneously frequency doubling 1.064μm light. We have demonstrated that a periodic DC electric field is capable of inducing this frequency doubling in glass if the periodicity is correct for quasi-phasematching. We have been able to selectively excite different SH waveguiding modes by varying the electrode periodicity. The planar waveguide geometry of the device makes it suitable for integration into an integrated optical device.

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References

1 ÖSTERBERG, U., and MARGULIS, W.: 'Dye laser pumped by Nd:YAG laser pulses frequency doubled in an optical fiber', *Opt. Lett.*, 1986, **11**, pp. 516–518

2 KESTER, J.J., WOLF, P.J., and WHITE, W.R.: 'Second-harmonic generation in planar waveguides of doped silica', *Opt. Lett.*, 1992, **17**, (24), pp. 1779–1781

3 STOLEN, R.H., and TOM, H.W.K.: 'Self-organized phase-matched harmonic generation in optical fibers', *Opt. Lett.*, 1987, **12**, pp. 585–587

4 KASHYAP, R.: 'Phase-matched periodic electric-field-induced second-harmonic generation in optical fibers', *J. Opt. Soc. Am. B*, 1989, **6**, (3), pp. 313–328

5 LEVINE, B.F., and BETHEA, C.G.: 'Second and third order hyperpolarizabilities of organic molecules', *J. Chem. Phys.*, 1975, **63**, (6), pp. 2666–2682

Engineering of barrier band structure for electroabsorption MQW modulators

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Indexing terms: Band structure, Electroabsorption modulators, Semiconductor quantum wells

The introduction of tensile strain to the barriers of InGaAsP multiquantum well, λ = 1.55μm, electroabsorption modulators is proposed. It decreases the valence band barrier height, and heavy hole escape time, which greatly increases the optical saturation intensity leading to smaller, lower capacitance modulators with greater power handling capabilities.

External optical modulators are very useful for avoiding the chirp associated with the direct modulation of semiconductor laser diodes used in long distance high bit rate systems. Multiquantum well modulators are attractive because they have a greater band edge shift than bulk Franz-Keldysh modulators allowing lower drive voltages compatible with high speed electronics. However, the barriers that enhance the band-edge shift also decrease the saturation intensity of the modulator if improperly designed [1]. In this Letter, tensile strained barriers for MQW modulators are proposed to increase the hole escape rate and thereby increase the optical saturation intensity. Tensile strained wells have been proposed to increase the absorption and saturation characteristics fo MQW materials by increasing the density fo excitable states [2]. An increase in saturation intensity is needed for shorter, lower capacitance, high speed modulators, and for improved optical power handling to extend repeater spacing and induce optical fibre nonlinear effects such as solitons.

The optical saturation of quantum well materials is caused by carriers in the well occupying all the excited states. By increasing the escape rate of the carriers the saturation intensity can be increased. To take advantage of the sharp exciton resonance, however, the carrier escape time cannot be reduced below the exciton lifetime which is ~100fs for the InGaAsP material system at room temperature. Improving the thermal emission and tunnelling rate are the most practical methods of decreasing the carrier escape time because recombination is slow, and adding impurities to accelerate recombination will destroy the exciton resonance. Making the barriers thinner or increasing the applied electrical field will reduce the tunnelling time of both the electron and holes simultaneously. The heavy hole escape time is generally much longer than the electron escape time due to the relatively large valence band offset and heavy hole mass in the InGaAsP system. Increases in the saturation intensity have been demonstrated by decreasing the valence barrier height through the introduction of aluminum into the barrier [3]. By using tensile strain, the problems of introducing aluminum into the growth chamber, and its associated device reliability issues can be avoided. In addition, tensile strain in the barrier can compensate for the compressive strain in the quantum well which has been used to enhance the band edge shift [4].

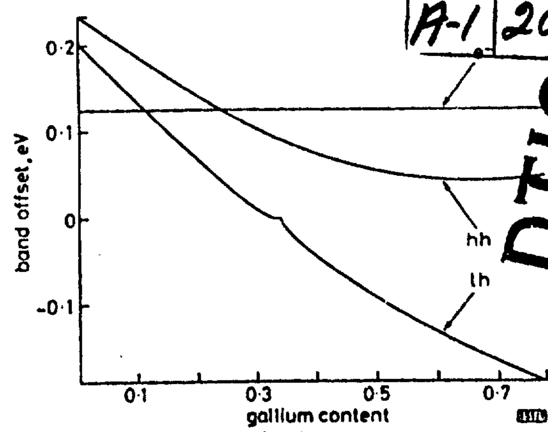

Fig. 1 ***Effective barrier heights for electron (e), heavy hole (hh) and light hole (lh), taking into account energy quantisation in well and strain effects in well and barrier***